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NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA
DEVELOPMENT MODEL OF A MAGNETIC PARTICLES DISPLAY
BY: LL LEE MAGNAVOX GOVERNMENT AND INDUSTRIAL
ELECTRONICS COMPANY FORT WAYNE, INDIANA

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MICROCOPY RESOLUTION TEST CHART

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Contractor Report 121

DEVELOPMENT MODEL OF A MAGNETIC PARTICLES DISPLAY

L. L. Lee
Magnavox Government and Industrial Electronics Company
Fort Wayne, Indiana

22 June 1982

Prepared for
Naval Ocean Systems Center

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NOSC

NAVAL OCEAN SYSTEMS CENTER
San Diego, California 92152

NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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Silicone rubber

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The technique utilized in fabricating a demonstration magnetic particle display panel of 100 X 100 addressable pixels on a 4" X 4" viewing area.

OBJECTIVE:

The objective of this activity was to fabricate a demonstration Magnetic Particle Display Panel of 100x100 addressable pixels on a viewing area of approximately 4" x 4". This was achieved and delivered to NOSC on 25 January 1982. The techniques utilized in fabricating the panel is described herein.

INTRODUCTION:

The Magnetic Particles Display forms images on a panel of freely rotating spherical particles, each of which is a tiny permanent magnet, dark colored in one hemisphere and light-colored in the other. Thus the amount of ambient light reflected by the particles is a function of the particle's orientation which is in turn controlled by a magnetic field. The magnetic field is controlled by a nearby not-so-permanent magnet array that functions as a memory. Sites in the memory are selectively magnetized by currents through conductors imbedded in the display similar to the switching of computer memory cores by coincident pulses of currents. Schematic sketches of the magnetic particles and construction of the display are shown in figures 1 and 2.

MAKING THE MAGNETIC PARTICLES

The particles were made of a material consisting of 40% Strontium ferrite (as a fine powder) in a polyethylene matrix. An extrusion of premixed materials was fed onto a heated, rotating disc, and was thrown off by centrifugal force. Surface tension forces the free-falling droplet into spherical shapes. The droplets cool and solidify into spherical particles of uniform size as they continue to fall. The size of the particles was controlled by adjusting the rotating speed of the disc.

SILVERING AND MAGNETIZATION

The particles were first etched in a solution of 86% H_2SO_4 and 8% CrO_3 in water. Etching for a few seconds is sufficient to make the polyethylene surface of the particles hydrophillic. This improves adhesion of the silver to the particle.

The particles were floated as a monolayer on the interface between Hexane and a solution of Silver Nitrate after being magnetized in the direction of the colored hemispheres. The particles are suspended on the surface and prevented from sinking by the surface tension. The silver adheres to the lower hemisphere and thus forms the reflective surface for the display.

The particles are then removed from the silvering interface, washed in ethanol and dried on a sheet of filter paper.

PRINCIPLE OF IMAGING BY MAGNETIC PARTICLES

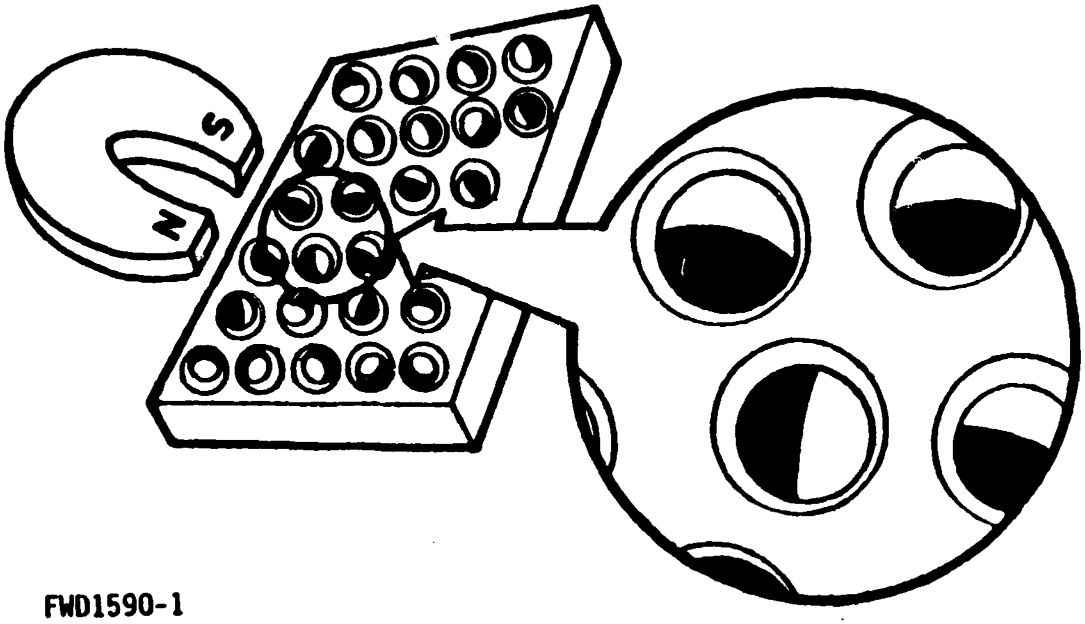

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Figure 1. Principle of imaging by magnetic particles .

CONSTRUCTION OF A MAGNETIC PARTICLES DISPLAY

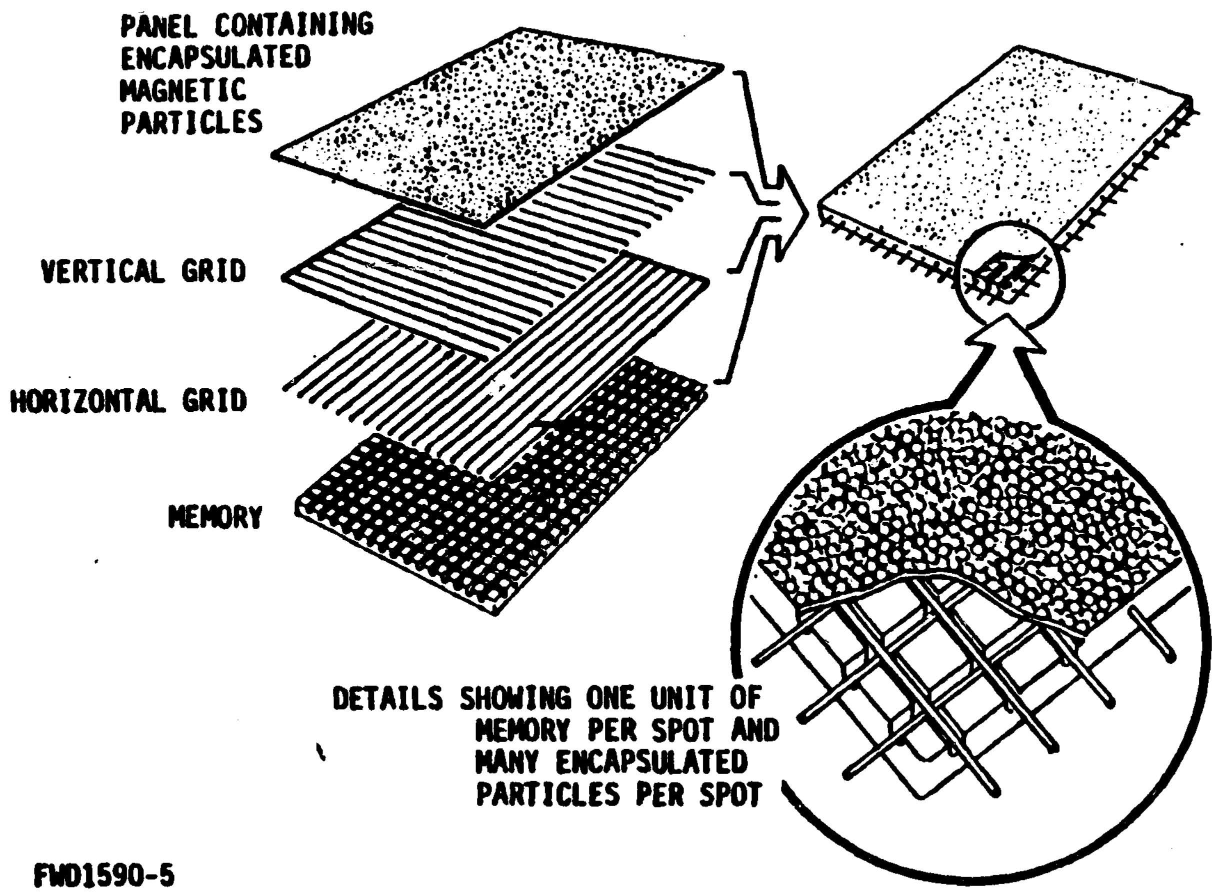

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Figure 2. Construction of a magnetic particles display

For increasing the particles' sensitivity, they are partially demagnetized by the application of an AC magnet field of very large initial strength but gradually and smoothly reduced in amplitude to zero. The final magnetization is determined by the DC bias superimposed onto the AC demagnetization field.

For this demagnetization process, the particles must be first aligned in the direction of the DC bias field and held firmly in that position during demagnetization. This was accomplished by placing the particles in a cup with tetradecane. The cup was placed at the poles of the demagnetization magnet. A DC Magnetic field in the same direction of the final DC bias (but of higher strength, enough to align the particles) was applied and kept active while a jet of liquid CO_2 is directed towards the cup causing the tetradecane to freeze. Once frozen, the DC field may be decreased to bias level and the particles may be demagnetized.

ENCAPSULATION

For this encapsulation process, the particles are placed inside a sheet of silicone rubber. After curing, the rubber is soaked in silicone oil which acts as a plasticizer causing expansion of the rubber and enabling rotation of the particles.

The uncured silicone rubber (DC3145) is first diluted in Freon 113 (1 gm silicone rubber per 15 ml of Freon). To this mixture, 0.15 cc of span 85 is added. The span 85 is a surfactant, it attaches to the interface between the particles and the surrounding liquid thus preventing firm adhesion between the silicone rubber and the particles. This enables the particles to become free later when plasticizer is used.

The diluted silicone rubber is sprayed onto a non-sticking surface (such as polyethylene). A thin film is formed. The freon is allowed to evaporate. At this moment, the surface is quite sticky and particles will adhere to it. Particles are sprinkled onto this surface. A weak, low frequency magnetic field (100 gauss at 60 hz) is applied causing the free particles to jump. The particles keep jumping until they come into contact with the sticky surface of silicone rubber, then they get stuck. By using an excess of particles, the surface of silicone rubber eventually becomes fully covered by a monolayer of particles. The layer has a random distribution that is statically uniform.

After one such layer of particles have been formed, the surface is again sprayed with silicone rubber diluted by Freon 113 and Span 85. After spraying, the Freon is allowed to evaporate. The surface is now sticky again, and another layer of particles may be applied if desired. In the display delivered, four layers of particles were applied by successive repetition of the above process.

After the silicone rubber has cured the sheet is placed in a bath of silicone oil (DC200 - 5 cst) to soak, expand and plasticize. The oil diffuses in fast initially but gradually slows down. Expansion is not complete until after several days of soaking. Most particles would appear to be still stuck. A majority of them can be made free by vigorous agitation in an ultrasonic cleaner. Then the sheet of encapsulated particles can be used in displays.

ADDRESSING MATRIX AND MEMORY

The addressing matrix and memory are fabricated on a sheet of printed-circuit board with holes drilled at the positions of the pixels. The supporting board is .030 inches thick of G10 fiberglass. An identical pattern is drilled on a sheet of .010 inch thick. Mold release material is sprayed onto the .010 inch sheet and the thick and thin boards are positioned together with holes lined up. A mixture of 66% Lithium-Nickle Ferrite ($Li_{0.45}\ Ni_{0.10}\ Fe_{2.45}\ O_4$, Philips SL397 IV) in an epoxy binder is spread over the PC boards and pressed into the holes. After the epoxy has set, a sheet of high-permeability material (.003 inch μ metal) is glued onto the .030 inch board side of the PC board sandwich. The .010 inch pc board is then peeled off. The remaining structure consists of the .030 inch board with 10,000 small LiNi ferrite magnets partly imbedded into the drilled holes. The parts of these magnets that are not imbedded were in the holes in the .010 inch pc board, now they are left sticking out to a distance of about .010 inch; that gives the entire structure an appearance of a ping-pong paddle.

Insulated wires were laid into the space between the protruding memory magnets to form the addressing matrix. Two strands of #38 wires are used for each conductor in the x or in the y directions. The double strand construction enables the wires in the x and y directions to be brought into closer proximity with each other without excessive increase of wire-resistances. The top of the wire matrix is approximately flush with the top of the memory magnets.

ASSEMBLY OF THE DISPLAY

The wires in the addressing matrix are soldered to connectors. The sheet of silicone rubber encapsulated magnetic particles are placed over the addressing matrix and memory assembly. A protective sheet of 1/16 inch polycarbonate is placed at the viewing side of the display, and after removing air bubbles from the excess oil, the edge of the display is sealed with epoxy resin.

EVALUATION OF THE DISPLAY

Images can be written into the display by passing electric current pulses through pairs of wires in the x and y directions. A simple addressing circuit was constructed to generate these current pulses. A schematic of this circuit is shown in figure 1. Selection of the addressed pixel is accomplished by manually plugging into connectors. The pattern of figure 2 was laboriously written-in that way. A sketch of the current pulse as observed in an oscilloscope is shown in figure 3. The pulse shape and width are not critical, as long as the current stays around its peak value for more than half a microsecond. The peak current that gave the best result is 14 amps. Observable switching can be made with current as low as 9 amps, however, with lower current; the image has lower contrast. With higher currents the crosstalk becomes more objectionable; -- at 18 amps, a very distinct cross pattern is observed.

Resolution of the display is 103 x 103, center-to-center distance between lines is 1 mm.

There are some mistakes made in the external connections to the display, all but one line-mistake can be corrected by using the correction diagram which accompanied the display at the time of delivery. In addition to the line defect, there are also some areas where the contrast is lower than normal. These include areas near the letters "NE" in "MAGNETIC" and the letters "SP" in "DISPLAY", and one area among the concentric lines where contrast is so low that it must be considered unreadable. There is also a small black spot within the big circle near the letter "O" in "NOSC". The areas of poor contrast are probably caused by poor distribution of ferrite. It is well known among plastic magnet manufacturers that at least 85% ferrite should be used; however, because of the lack of material-handling equipment, we were not able to handle mixtures with over 70% ferrite. Furthermore, in mixing the ferrite and epoxy, air bubbles are introduced into the composite material causing poor performance. These problems are expected to be easily solvable by the use of better fabrication equipments.

Contrast of the display was measured with a Pritchard photometer. The measurement was made under direct sunlight through a window. A circular area approximately 3/4 of the area of a pixel is measured. The maximum contrast is obtained by finding the brightest and least bright areas in the display. The contrast ratio is 3. The sunlight falls on the display at an angle of approximately 55° to the normal. The contrast is practically the same whether the photometer is normal to the display or at 45° to the normal. The "white" part of the display was measured to have brightness of 170 foot lambert. By comparison, when a sheet of white paper is placed in the position of the display, the brightness was 880 foot lambert. Therefore the best "white" reflects only about 20% of the incident light.

The two principal reasons for low whiteness and contrast are
1) Not all the particles are free to rotate, some are stuck to the encapsulating silicone rubber. The sheet of encapsulated particles used

in the delivered display was the second of such large area sheets ever made. The amount of surfactant used was minimized to reduce weakening of the rubber sheet material. In later fabrications, higher concentration of surfactants were used making more particles free to rotate. The rubber is still strong enough for use in displays. 2) The silicone encapsulation material expands to more than three times its original area when plasticized. The expansion cannot be controlled. Such a large amount of expansion results in a three-fold reduction of the final particle density. Other materials with less expansion should be used for increase of contrast. The use of PVA plasticized by Toluene is reported by Saitoh et al of Sony. We have tried PVC plasticized by DOA in which case the expansion was to less than two times the area. With such developments, display of this type can be made to have much higher contrast.

A digital clock using magnetic particles encapsulated by the Xerox method was fabricated in 1976 for demonstration to the auto manufacturers. That display is still working. Therefore this type of displays can be expected to have long life.

Ref 1) A Magnetic-Particles Display
L.Lee IEEE trans on Electron devices
ED22, #9 1975

Ref 2) Fabrication of Magnetic Particles Displays
L. Lee Proc SID 18 3&4 1977

Ref 3) L. Lee Magnetic Particles Display
Fabrication
SID 1980 International Symposium
(digest pp 128-129.)

Ref 4) Sheridon & Berkovitz The Gyricon - A twisting Ball Display
Proc SID 18 3&4, 289-293 (1977)

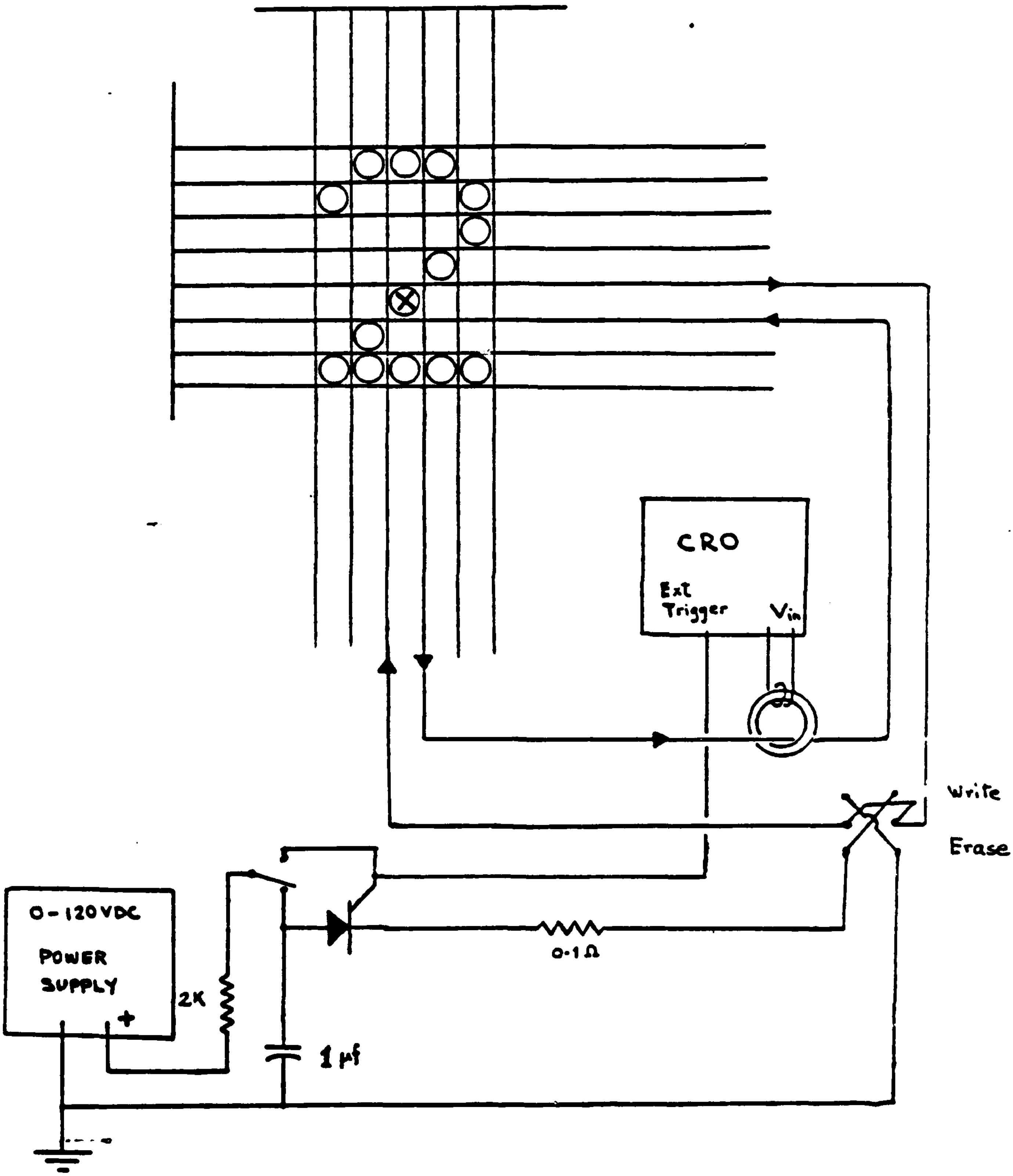
CRO
Ext
Trigger
Vin
Write
Erase
0-120VDC
POWER
SUPPLY
+
2K
1 μf
0.1 Ω

Figure 1

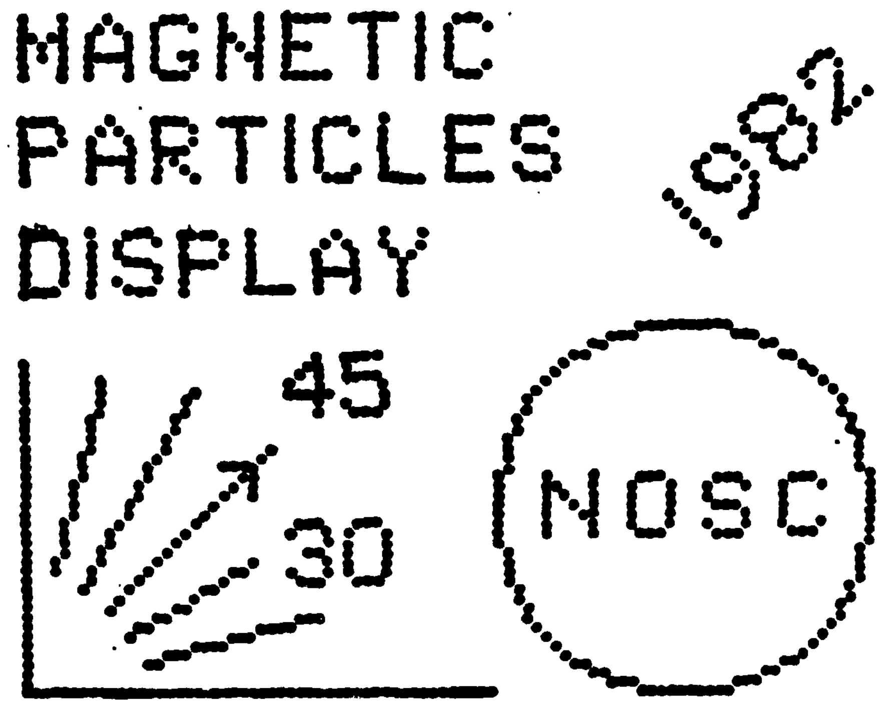

Figure 2

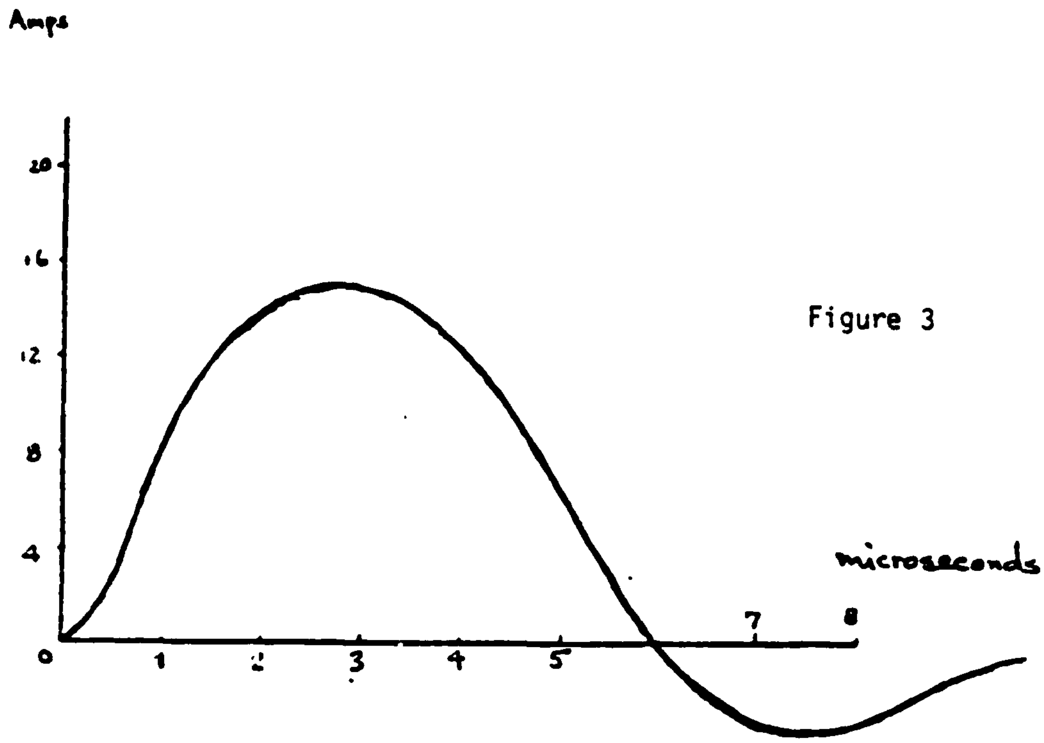

Figure 3

TYPICAL PULSE SHAPE

MAXIMUM INSTANTANEOUS CURRENT	DISPLAY IMAGE
9 Amps	Starts being observable
12-15 Amps	Preferred operating range
18 Amps	Crosstalk objectionable

RESISTANCE OF WIRES: 0.2Ω per wire
0.8Ω 4 wires

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SEPT. 28, 1982